THE GABBROS AND ASSOCIATED INTRUSIVE ROCKS OF HARFORD COUNTY, MARYLAND

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A dissertation submitted to the Board of University Studies of the Johns Hopkins University in conformity with the requirements for the degree of Doctor of Philosophy

BY

HERBERT INSLEY

1919

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THE GABBROS AND ASSOCIATED INTRUSIVE ROCKS OF HARFORD COUNTY

INTRODUCTORY

The area of gabbro and related basic igneous rocks which is discussed in this paper lies within the borders of Harford County, Maryland. It has a length within the County of about eighteen miles, and varies in width from $1\frac{1}{2}$ to $3\frac{1}{2}$ miles. In general the area has a northeast-southwest strike. To the south of this main gabbro belt there is another area of irregular outline consisting of rocks of gabbroic composition. (Plate I.) This paper deals only with the northern gabbro belt. The Susquehanna River cuts across the northern gabbro belt at the eastern boundary of the County, but beyond the river the same rocks form a belt through Cecil County (Maryland), Delaware and eastern Pennsylvania. At the southwestern end of the area, about $1\frac{1}{2}$ miles from the boundary between Baltimore and Harford counties, the gabbro pinches out or disappears beneath the Baltimore gneiss, although it reappears again in Baltimore County only a few miles distant. Still farther to the south, in Virginia, North Carolina and South Carolina, gabbro areas are found, but they usually occur only as small, isolated patches.

All of the gabbros of Virginia, Maryland, Delaware and Pennsylvania are included within that portion of the Middle Atlantic Slope known as the Piedmont Plateau. The Middle Atlantic Slope is usually considered as that section of the eastern United States which sheds its waters directly into the Atlantic Ocean, and in which the principal rivers rise within the Appalachian Mountain system.[1] It is separable into three distinct zones—the Appalachian Mountains, the Piedmont Plateau and the Coastal Plain.

The Piedmont Plateau stretches to the northeast into New Jersey. Here it merges, in an indefinite way, into the New England Plateau. To

[1] McGee, W. J., Am. Jour. Sci. (III), vol. xxxv, 1888, p. 120.

the south it reaches as far as Alabama. Throughout its length the Plateau is approximately parallel to the Atlantic coast line. This region is bounded on the west by the Appalachian Mountains. In Maryland and Virginia the boundary is represented by the long, narrow crest of the Blue Ridge. To the east the rocks of the Piedmont Plateau disappear beneath the flat-lying sediments of the Coastal Plain. The rivers, which usually have a steep gradient in the Plateau, find a much flatter surface when they reach the Coastal Plain, and thus they show different types of valleys in the two areas. In the Piedmont Plateau of Maryland the master-streams often cut directly across the strike of the principal rock formations. These streams are characterized by valleys with steep slopes, often exhibiting entrenched meanders. Deer Creek in Harford County is an excellent example of such a stream. In general the master-streams are superimposed, showing no relation at all to the structure of the rocks over which they flow. The tributaries, however, are more often consequent upon the structure of the rock formations of the region.

The Piedmont province as a whole is a highly dissected plateau sloping gently to the eastward. The scenery, especially in Maryland, is characterized by rolling hills and broad, fertile valleys. Throughout the region, particularly in the areas occupied by gabbros and granitic rocks, there is a very heavy mantle of soil. This makes geological field-work especially difficult, as outcrops are scarce. Often one finds areas covering three or four square miles where the character of the underlying rock is only indicated by the nature of the soil and a few small boulders scattered on the surface. Because of this, the location of boundary lines of rock formations has often been somewhat arbitrary.

It is the purpose of the writer in this paper to give detailed descriptions of petrography and structure only where they will throw some light on the relations of the different rock masses and give some clue to the cause of the different contact phases of the gabbro that have been developed. The unravelling of these difficulties has been hindered by the lack of good rock exposures and by the complex structure that is everywhere characteristic of the Piedmont Plateau.

AREAL DISTRIBUTION OF ROCK TYPES

Geological work in Harford County has been carried on at various times within the last twenty-five years by the Department of Geology of the Johns Hopkins University and by the Maryland Geological Survey. In this way an idea of the formations in the County has been formed and a map has been published by the Maryland Geological Survey showing the general distribution of the rocks. Thus far, no very detailed work has been done except in the serpentine areas.

The Piedmont Plateau of Harford County may be roughly divided into two parts—northwestern and southeastern. The rocks of both these sections never fail to show the effects of regional matamorphism. Sometimes the pressure has been so great as to completely obliterate all traces of original characteristics. In a general way, however, most of the northwestern section is composed of rocks that were originally sedimentary, while the metamorphosed rocks of the southeastern section were principally intrusive in origin.

Quartzites, Marbles and Slates

Most of the northwestern section is made up of mica schists and phyllites, but there are two small areas of other rocks. At the western boundary of the County there is an inlier of Baltimore gneiss, surrounded by quartzite. The quartzite is lithologically related to the Setter's quartzite, often considered to be of Lower Cambrian age, which shows extensive exposures in Baltimore County. The quartzite consists of quartz and muscovite in thin layers. Well developed slender tourmalines, sometimes stretched by movements of the rock, are characteristic of this formation.

Bordering the quartzite area on the southeast is a small area of marble and metamorphosed limestone. Marble and limestone of the same age have been named Cockeysville in Baltimore County. Phlogopite is a very prevalent constituent of this rock. What scanty evidence is available seems to indicate that this formation also is of Lower Cambrian age.

Another small area, an outlier of rocks somewhat younger than the mica schist, is found at the northern boundary of Harford County near Cardiff. This area consists of quartzite and quartzose conglomerate overlain by slates. The quartzites are metamorphosed limestones, dolomites, and limestone breccias. The Peach Bottom slates which overlie the quartzites are extensively quarried for roofing slate near Delta, Pennsylvania, just across the Maryland-Pennsylvania border. Both formations have been provisionally assigned to the Upper Silurian.

MICA SCHIST AND PHYLLITE

By far the most prevalent rock in the northwestern section is the mica schist. The chief mineral in this rock is generally sericite or muscovite, arranged with the long axis parallel to the schistosity. Quartz, feldspar, and epidote are often associated with the mica. Garnets are very abundant, although they may be considered as an accessory constituent. The effects of powerful and long-continued regional metamorphism are well shown by the intricate crinkling and folding of the laminations of the schists. There seems to be no doubt that these schists were originally argillaceous sediments, now greatly altered both in appearance and mineral content by regional metamorphism. The age of the mica schist is still undecided. If the formations which underlie it, the Setter's quartzite and Cockeysville marble, are Cambrian, and the overlying formations, the Cardiff quartzites and Peach Bottom slates, are of Upper Silurian age, then the mica schist lies somewhere between the two. The evidence bearing on the age of any of these metamorphosed formations is at best fragmentary and inconclusive. If this schist is to be correlated with the Wissahickon of Pennsylvania, to which some of the evidence points, then the age may be pre-Cambrian.[2] The strike of this formation is quite uniformly east of north. The dip of the stratification, when shown, is to the southeast, and varies from 30° to 80°.

[2] Bliss, E. F. and A. I. Jonas, U. S. Geol. Survey Prof. Paper 98B, 1916.

SERPENTINE

Within the mica schist area as well as in the main gabbro belt, dikes and small stocks of intrusive material, now wholly altered to serpentine, are common. There is no doubt that the serpentines were originally intrusive peridotites and pyroxenites, now thoroughly altered by regional metamorphism. A short description of the serpentine will be given in the chapter on petrography.

BALTIMORE GNEISS

South of the main gabbro belt there are four long, rather narrow belts of rock of gneissic character. These rocks are considered to be the oldest (pre-Cambrian) of any in the whole Piedmont Plateau of Maryland, and are grouped together under the name of Baltimore gneiss. Long-continued regional metamorphism has so acted upon them that their original character has often been entirely obliterated. All the evidence available seems to show that they consist of an igneous complex with inclusions and intercalations of sedimentary rocks.[3] These gneisses vary in composition from a very acidic biotite granite to a very hornblendic diorite. Rocks of the same character are found in Baltimore County to the southwest and in the region about Philadelphia to the northeast.[4] The gneissic structure shows a northeast strike, parallel in general to the trend of the formations of the Piedmont Plateau. Its general dip where determinations can be made is to the southeast.

GRANITE

Granites are also found occupying large areas in this region. In composition they vary from typical biotite granites to granites carrying considerable amounts of hornblende. In places they exhibit a decidedly gneissic phase, while elsewhere the mineral grains are unoriented and the granite appears as the ordinary massive phase. Although orogenic movements have undoubtedly affected these granites, they nowhere show the tremondous effects of pressure exhibited by the Baltimore

[3] Williams, G. H., 15th Ann. Rept. U. S. Geol. Survey, 1894, p. 665.
[4] Bascom, F., U. S. Geol. Survey Phila. folio (No. 162), 1909.

gneiss and the mica schist. Keyes[5] and Williams,[6] who studied the granites of apparently the same age in Baltimore County, consider them to be much younger than the Baltimore gneiss and even younger than the gabbro. Granite is found principally in the region south of the main gabbro belt, althought there is a narrow strip of it extending for some distance along the northern border of the gabbro. Like the other formations of the Piedmont region, the granites show a northeast-southwest trend.

GABBRO

Two extensive areas composed of rocks of gabbroic composition are found in Harford County. To the southeast there is a large area with an irregular outline but showing to some extent the same northeast-southwest trend revealed by the other formations of the Piedmont Plateau. Remnants of sediments of Mesozoic and Cenozoic age belonging to the Coastal Plain formations are found overlying the gabbro in this area. The other gabbro area has been referred to in preceding pages. It is a long, narrow belt showing to a marked degree the same northeast-southwest trend. Belair, the county seat of Harford County, lies within the boundaries of this belt. In both areas the gabbro is of two types—(1) the original hypersthene gabbro, and (2) meta-gabbro containing secondary hornblende and other alteration products. As will be shown in a later chapter the meta-gabbro has undoubtedly been derived from the hypersthene gabbro. Both types, with their intermediate forms, will be described in detail in the chapter on petrography. Here as elsewhere in the Piedmont Plateau orogenic movements have profoundly altered the rock but nowhere does the gabbro show the marked degree of alteration exhibited in the Baltimore gneisses. At present there is no decisive evidence as to the form of this intrusive magma, whether a batholith, a laccolith, or a sill. Its long, narrow form, and the shape of the intrusive bodies which border it on the north, would suggest that this body is a sill. The fact that the structures of the

[5] Keyes, C. R., 15 Ann. Rept. U. S. Geol. Survey, 1894, pp. 685–740.
[6] Williams, G. H., Idem, pp. 657–684.

adjoining formations have in general a northeast strike and a dip to the southeast would also suggest that this magma had been intruded along a plane of weakness, and that it also probably dips now in a southeast direction. Certain surface indications are characteristic of these gabbro areas. Polygonal blocks with a coating of rusty-red, clay-like substance strew the ground in these areas. Often the interior of these blocks is found to be remarkably fresh, with little or no weathering effects. The soil, too, is often characterized by a deep red color, although sometimes, on account of variation in composition of the gabbro, the soil has a light buff color.

CONTACT ROCK

At or near the contact of the gabbro with the Baltimore gneiss there are outcrops of limited extent, of contact rocks varying in composition and texture. These will be considered in detail in the chapters dealing with petrography and contact phases.

DIKES AND VEINS

In Cecil County, just to the east of Harford County, a number of diabase dikes have been mapped. Thus far only four have been discovered in Harford County, all of these lying within the main gabbro belt, with the possible exception of one, which may extend across the contact into the granite. These dikes, as well as those of Cecil County, have a general northeast-southwest strike, thus parallelling the trend of the other formations of the region.

Pegmatites of the usual coarse-grained variety, consisting of quartz, feldspar (orthoclase and albite), mica (biotite and muscovite), and some accessory minerals, are found in a few places in Harford County, particularly along the Susquehanna River. One large pegmatite dike has been intruded into the gabbro and is very well exposed in the cliff at the edge of the Susquehanna River about a mile north of Castleton. The relation of the pegmatites to the gabbro will be discussed in another place. Although pegmatites may be present in many places in the gabbro area, they are concealed by the heavy mantle of soil. Apparently pegmatite

dikes are fewer in number in Harford County than in Cecil County, where at least thirteen dikes have been mapped.

Quartz veins are numerous throughout the whole Piedmont region in Harford County. Usually their presence is indicated only by the abundance of quartz boulders which strew the surface of the ground in the vicinity of the veins. These boulders are composed almost wholly of white sugary quartz. The veins were undoubtedly formed by deposition from circulating waters in cracks or fissures caused by orogenic movements.

PETROGRAPHY

A petrographical description will be given of only those rocks intimately related to the gabbro in composition or closely associated with it in areal distribution.

HYPERSTHENE GABBRO

Hypersthene gabbro is the prevalent and typical rock of the main gabbro belt. A peculiar feature of this area is the absence of true norites, which are typical of the gabbro areas of Cecil County,[7] Delaware,[8] and eastern Pennsylvania.[9] On the other hand, true gabbros are also absent, hypersthene always being present in such quantities that it must be considered as an essential constituent. Hypersthene gabbro merges almost imperceptibly into meta-gabbro. Small quantities of hornblende are present in practically every specimen, so that a real distinction cannot be made in this region between hypersthene gabbro and meta-gabbro.

The presence of gabbro in a region is usually indicated by the large quantity of polygonal blocks with a rusty-red weathering surface strewn about on the ground. The soil as well often has a characteristic red color. The fresh specimens of hypersthene gabbro vary greatly both in color and size of grain. The grain of the rock often changes abruptly

[7] Bascom, F., Maryland Geol. Survey, Cecil County, 1902, p. 125.
[8] Chester, F. D., U. S. Geol. Survey, Bull. 59, 1890, p. 22.
[9] Bascom, F., Philadelphia folio, 1909.

from coarse to fine. Individual mineral particles, however, rarely reach a length of more than a centimeter. Color may vary from light gray to very dark gray. A purplish tinge is very characteristic of unaltered hypersthene gabbro. The variation in color is due to the relative amounts of the mineral constituents present in the specimen. Although gneissic structure is often prominent in formations adjacent to the gabbro and in some of the contact facies of the gabbro, it is the exception rather than the rule within the main gabbro body. Feldspar, diallage, and hypersthene can be identified in hand specimens of hypersthene gabbro without the aid of a microscope.

Under the microscope the rock is seen to be holocrystalline, the individual mineral constituents showing allotriomorphic to hypidiomorphic forms. The essential primary mineral constituents of the hypersthene gabbro are basic plagioclase, hypersthene, and diallage. The relative amounts of these constituents vary considerably. Often a thin section shows a composition of 80 per cent plagioclase. At other times the specimen is composed almost wholly of hypersthene and diallage. At such times the rock is really pyroxenite and not hypersthene gabbro.

The accessory primary constituents of the hypersthene gabbro are magnetite, apatite, quartz, and pyrite. Except in the contact phases, quartz is never abundant enough to be considered an essential constituent. The accessory minerals often occur as minute inclusions within the other minerals. Apatite, especially, is usually found included within the plagioclase crystals.

The plagioclase commonly has an allotriomorphic form. Maximum extinction angles measured on sections at right angles to (010) give values of 40° to 45°, corresponding to compositions of Ab_3An_7 to Ab_2An_3. The plagioclase is therefore an acid bytownite. Polysynthetic twinning lamellae formed after the albite law are very common in all fresh individuals. At times combinations of twinning after both pericline and albite laws are seen. Inclusions in the feldspar are very common. Often these are dust-like particles, which are present at or near the center of the crystal. The particles are so minute that optical determination is not possible. Apatite inclusions are abundant.

Hypersthene is allotriomorphic as a rule, although hypidiomorphic individuals have been observed in specimens that seem to show a slightly different type of crystallization from that usually found in the hypersthene gabbro. The parallel extinction and strong pleochroism, greenish to reddish brown, distinguish hypersthene from diallage, with which it is constantly associated. Well-developed cleavage planes parallel to (110), (100), and (010) are characteristic of the mineral. Inclusions of magnetite and hair-like needles arranged along cleavage lines are common. Williams[10] concluded that the peculiar metallic reflection seen in many thin sections was due to inclusions of plates of a reddish-brown color lying parallel to the brachypinacoid. These plates were regarded as brookite by Kosmann.

Diallage usually occurs in allotriomorphic, irregular grains, rarely hypidiomorphic. It shows a faint, light green color under the microscope, without any apparent pleochroism. Diallage may be recognized by the prismatic cleavage and well-developed parting parallel to the orthopinacoid. A secondary parting parallel to the clinopinacoid is sometimes present. Maximum extinction angles in sections parallel to the clinopinacoid have a value of 39°. Inclusions are not common in diallage.

Magnetite and apatite are the most common accessory constituents. Although they are often abundant they rarely occur except as minute particles. Apatite is frequently an inclusion in plagioclase, where it can be observed in sharply defined, idiomorphic crystals. Quartz and pyrite sometimes occur as primary accessory constituents, although quartz is frequently found in veinlets running through the rock. Garnet has been observed only in one or two sections of hypersthene gabbro. It is sometimes quite abundant, however, in contact phases. Olivine has never been noted in specimens of hypersthene gabbro from Harford County, although it has been described in a few instances from both Cecil and Baltimore counties.

[10] Williams, G. H., U. S. Geol. Survey Bull. 28, 1886, p. 24.

META-GABBRO

The term meta-gabbro is used here to indicate those rocks derived from hypersthene gabbro by processes of meta-morphism alone. Exposures of meta-gabbro are found distributed within the gabbro area in a most irregular manner. Although meta-gabbro may very well have some relation to zones of greater pressure in the region, the localities containing this rock seem to have no regular arrangement. The transition from true hypersthene gabbro to meta-gabbro is not marked. Almost every specimen of hypersthene gabbro shows the presence of at least a small amount of secondary hornblende. Megascopically the change is not noticeable unless hornblende becomes prominent, when the rock takes on a green color and fibrous hornblende can be seen without the use of the microscope. A milky appearance of the feldspar also indicates that a metamorphic change has taken place.

Under the microscope this change can be observed in all stages. Generally pyroxene is the first mineral to undergo alteration. The method of alteration of hypersthene differs slightly from that of diallage. The work of Williams[11] has shown that hypersthene requires the presence of plagioclase to effect its alteration to green hornblende, the lime and alumina of the plagioclase being necessary for this transformation. The formation of a double rim around hypersthene individuals has often been observed. The inner rim is composed of colorless, fine needles arranged at right angles to the edge of the hypersthene crystal, while the outer one is green with all the characteristics of fibrous or compact green hornblende. An analogous colorless rim around olivine has been called tremolite by Tornebohm.[12] Finckh[13] noted the same double alteration rim around pyroxene in the gabbro of northern Syria. He also called the inner rim tremolite. All the optical properties of these inner colorless rims as observed in the thin sections seem to agree with those of tremolite. Alteration may continue until the hypersthene has entirely disappeared, its place being taken by fibrous or compact hornblende, sometimes with a core of colorless tremolite needles.

[11] Williams, G. H., loc. cit., p. 42.
[12] Törnebohm, A. E., Beues Jahrb., 1877, p. 384.
[13] Finckh, L., Zeits. deutsch. geol. Gesell., Bd. L, 1898, p. 97.

The change of diallage to hornblende may be, and usually is, a direct one without the intervention of material from other minerals. As in hypersthene the change begins around the edges of the diallage crystal. The transformation then proceeds along cleavage cracks or other paths of least resistance. It is not unusual to find diallage crystals in a speciman entirely transformed to hornblende, with no trace of the original mineral remaining. Williams[14] concluded that in the case of diallage the change might not only be one of uralitization with chemical change, but also one of true paramorphism. He and others also found that the alteration product was sometimes brown hornblende. Brown hornblende has not been observed in specimens of Harford County gabbros. Rose[15] noticed that when augite changed to fibrous hornblende, magnetite and calcite often formed between the needles.

The secondary hornblende is easily recognized under the microscope by its striking pleochroism in greens and blues, and its cleavage angle of about 55° on the basal section in compact varieties. The arrangement of aggregates and the peculiar fraying out of fibers from the compact hornblende are characteristic of the fibrous variety.

The alteration of pyroxene to hornblende is a very common one in basic igneous rocks. Almost every occurrence of gabbro in regions where dynamic metamorphism has been active shows this change. Such an alteration was first noted by Gustav Rose in 1830. It was Williams who was first able to discover the true nature of this change by his detailed study of the gabbros in the vicinity of Baltimore (loc. cit.) the norites of the Cortlandt series,[16] and the greenstones of the Menominee and Marquette districts[17] (58). Since that work, this change has been observed by Finckh, Bonney, Miller,[18] Teall,[19] Loughlin, Hecker, and many others.

[14] Williams, G. H., Am. Jour. Sci., (III), vol. xxviii, 1884, p. 261.
[15] Rose, G., Zeits. deutsch. geol. Gesell. Bd. XVI, 1864, p. 6.
[16] Williams, G. H., Am. Jour. Sci. (III), vols. xxxi, 1886; xxxiii, 1887; xxxv, 1888; xxxvi, 1888.
[17] Williams, G. H., U. S. Geol. Survey, Bull. 62, 1890.
[18] Miller, W. J., Jour. Geol., vol. xxi, 1913, p. 168.
[19] Teall, J. J. H., Geol. Mag. dec. III, vol. i, 1886, p. 484.

It is generally thought that the transformation of pyroxene to hornblende is the direct result of dynamic action. In some instances, however, the change has probably been brought about by some kind of metasomatic replacement, although here too dynamic action undoubtedly prepared the way for the activity of the solutions.

Another important result of metamorphic action is the alteration of the basic plagioclase. This usually begins a little later than the change pyroxene to hornblende. The first change in the feldspar is often to a number of crystallites of epidote and zoisite. These form at about the same time. Usually the first formation of the secondary minerals is at or near the center of the plagioclase crystal. Sometimes, however, the epidote appears at the boundary of the plagioclase, apparently as a reaction product of the plagioclase and pyroxene. Epidote and zoisite, as a rule, have well-developed crystal faces. Both can be readily recognized by their relatively high indices of refraction, while zoisite is distinguished from epidote by its much lower double refraction, usually showing a peculiar blue interference color in sections of the ordinary thickness (.03 mm.). The chemical compositions of epidote and zoisite seem to indicate that they are formed as a result of both dynamic action and processes of weathering. Further alteration of the plagioclase results in the combination of minerals called saussurite. Microscopic examination of the Harford County gabbros shows saussurite to be composed of zoisite, epidote, and secondary albite. Cathrein[20] was the first to show that saussurite is usually composed of these three minerals with some accessory actinolite and tremolite. The secondary albite often occurs as large, clear, irregular grains without twinning, in which zoisite and epidote are included. In color, translucency, and occurrence, the albite resembles quartz very closely.

When the gabbro approaches a pyroxenite in composition, as it sometimes does, the product of metamorphism is a rock composed almost wholly of hornblende with some accessory epidote or zoisite. Megascopically this has something of the appearance of meta-gabbro, except that the green color is more pronounced, due to the greater development

[20] Cathrein, A., Zeits. Kryst. Min., Bd. vii, 1883, p. 56.

of fibrous green hornblende, and the white or colorless particles of feldspar are absent.

Veinlets of quartz and sometimes of albite traverse specimens of hypersthene gabbro and meta-gabbro. The veinlets show aggregates arranged in a mosaic fabric, indicating some crushing effects after crystallization has been completed. These depositions are only indirectly the results of dynamic effects, the pressure opening the cracks and thus allowing solutions to deposit these minerals in the veins.

In many places weathering has produced secondary minerals very different from those caused by the action of dynamic metamorphism. Chlorite is one of the most common of these products of weathering. It is quite usual to find small quantities of chlorite in both hypersthene gabbro and meta-gabbro, although it is most often found accompanying the secondary hornblende in the meta-gabbro. Chlorite is recognized by its occurrence as elongated plates or fibers in radiating or irregular aggregates. It is usually colorless, although green chlorite showing considerable pleochroism is sometimes seen. Between crossed nicols chlorite shows a distinctive, faint gray interference color of the first order. The combination of dynamic metamorphism and weathering may result in the formation of a chlorite-epidote rock in which sharply defined, colorless or pale-yellow crystals of epidote are surrounded by scaly or platy aggregates of chlorite. Such aggregates have been noted in other localities.[21] Pyrite is often found in small quantities in these altered gabbros as a product of weathering.

In the extension of the gabbro region in Baltimore County, Cecil County, Delaware and Pennsylvania, the products of dynamic metamorphism and weathering are found to be quite similar to those of Harford County. Williams was the first to describe the gabbros in the vicinity of Baltimore and to note the alteration to "gabbro-diorite." Later the basic rocks of Cecil County were described by Leonard[22] and Bascom[23] (1). "Gabbro-diorite" from Delaware has been de-

[21] Williams, G. H., U. S. Geol. Survey Bull. 62, 1890, p. 56.
[22] Leonard, A. G., Am. Geol., vol. xxviii, 1901, pp. 135–176.
[23] Bascom, F., Maryland Geol. Survey Cecil County, 1902, pp. 83–148.

scribed by Chester[24] (10), and a rock of the same character from the Philadelphia district has been described by Bascom.[25] In these localities chlorite has been found in the gabbros and in its alteration products.

SERPENTINE

North of the gabbro area as well as within the area itself there are a large number of serpentine bodies varying greatly in dimensions and shape. The largest body in part adjoins the gabbro area. It is thirteen miles long and about a mile wide. Other bodies vary in dimensions down to those only a few hundred feet in length. A detailed and careful study of the serpentine areas in Harford County has been made by Johannsen.[26] He concludes that most of the peridotites and pyroxenites from which the serpentine has been derived were intrusive into the other rocks of the region. The relations of the serpentine within and adjoining the gabbro area bear out this conclusion, for only in a few cases have transitions been found within the gabbro area between the pyroxenite and the hypersthene gabbro. Contacts are rarely exposed, but wherever found they are quite sharp.

Of the appearance of the mineral and the rock, Johannsen says:— "Megascopically it is a compact dirty-green to black mineral with a splintery fracture and a greasy or pearly to waxy lustre. The color of the rock depends upon the amount of pure serpentine present, and upon the amount of magnetite and chromite; the pure serpentine being of an oily-green color, but, with much finely divided magnetite, approaching a black. Chlorite gives it a dirty-green color. . . . . The mineral is often megascopically of a fibrous structure; sometimes it is laminated and is often interlaced with talc or chlorite. . . . . Serpentine often forms entire rock masses and is generally quite compact and massive, although at times it is schistose and thinly laminated. The color varies from green to yellow or brownish red and often shows clouds and streaks on account of the magnetite occurring in it. . . . . The rock

[24] Chester, F. D., U. S. Geol. Survey Bull. 59, 1890.
[25] Bascom, F., Philadelphia folio, 1909.
[26] Johannsen, A., This volume, part iii.

is composed primarily of the mineral serpentine but it generally also contains fragments of the mineral from which this was derived, such as olivine, bronzite, diallage, diopside and hornblende. Chlorite is often present in large quantities and gives the rock a dirty-green color."

Under the microscope, serpentine appears to be made up of fine fibers, thin prisms, or thin laminated plates. The index of refraction is low, the double refraction fairly low (about 0.013), and the extinction is parallel to the fibers. It may easily be confused with chlorite, especially when in fibers or plates. Serpentine is frequently associated with fibrous green hornblende and talc. Masses of hornblende in many instances are mingled with the serpentine in the same thin section. The hornblende is undoubtedly an alteration product of pyroxene. Talc is considered by some to be a weathering product of hornblende,[27] while by others it is considered as an alteration product of both serpentine and hornblende.[28]

Johannsen considers the serpentine of Harford County to be derived from four sources:—(1) feldspar-poor gabbros or pyroxenites, (2) pyroxene-amphibole-olivine rocks, (3) amphibole-olivine rocks, (4) pure olivine rocks. Serpentine cannot be considered as an alteration by paramorphism because of the difference in chemical composition between it and the rocks from which it has been derived. It is rather the result of some form of replacement by the action of solutions. It should, perhaps, be considered more the result of weathering processes than the result of dynamic metamorphism, although undoubtedly dynamic forces have crushed and shattered the original rock and thus made the alteration easy.

Cases of alteration of feldspar-poor gabbros to serpentine have not been observed by the writer, alteration usually resulting in a mixture of fibrous hornblende, chlorite, and epidote.

The presence of olivine within the gabbro area has not been observed, although traces of it have been found by Johannsen in several places within the serpentine areas. This fact is of some significance in deter-

[27] Williams, G. H., U. S. Geol. Survey Bull. 28, 1886, p. 58.
[28] Bascom, F., Maryland Geol. Survey, Cecil County, 1902, p. 134.

mining the age relations of the two bodies, and will be considered in another chapter.

BALTIMORE GNEISS

The Baltimore gneiss, already mentioned in the description of rock types of the county, adjoins the gabbro area for some distance to the south. It varies greatly in composition, in places being composed almost wholly of hornblende, or hornblende and mica, while elsewhere it is composed chiefly of quartz and feldspar. The gneiss often found near the gabbro contact is a very hornblendic phase containing feldspathic lenses or bands. The gneissic structure is usually quite apparent, although sometimes this rock is so extremely hornblendic that the structure is obscured. A number of thin sections were made from specimens of hornblende gneiss taken near the southwestern end of the gabbro area. The specimens vary in color from a dark gray to almost black, depending upon the relative quantity of hornblende present. Bands of feldspar and quartz are very numerous in some specimens, while in others they are almost entirely lacking. Hornblende, quartz and feldspar can be seen with the naked eye.

Under the microscope the hornblende gneiss is seen to be composed of compact green hornblende, acid plagioclase, and quartz. Accessory constituents are orthoclase, biotite and pyrite. The hornblende is always green and usually well crystallized with marked cleavages. The crystals are commonly arranged with their long axes parallel to the gneissic structure in the rock, and sometimes they have been bent and broken as the result of dynamic action. The feldspar is mostly acid plagioclase. Measurement of extinction angles shows it to have a composition of about $Ab_{85}An_{15}$, an acid oligoclase. Clear, glassy, untwinned feldspars are frequent. There is undoubtedly some orthoclase present. Quartz also is very abundant. Both quartz and feldspar are commonly arranged in mosaic patterns due to crushing of the rock. Pyrite, although an abundant accessory constituent, occurs only in fine particles. The plagioclase is often found undergoing alteration to epidote. At times the epidote crystals become fairly large, although

minute crystallites are more common. Chlorite sometimes occurs as a decomposition product of the hornblende.

GRANITE

Granite occurs in long, narrow belts with a northeast-southwest trend in areas north and south of the main gabbro belt. (Plate I.) Four isolated areas are found along the Susquehanna near Lapidum and Havre de Grace.

As a rule the granite is a light-gray to white rock, although in places segregations of biotite may give it a much darker color. The color is decidedly lighter than that of the average Baltimore gneiss. At times the granite develops a definite gneissic structure. This structure, however, is probably due to the formation of secondary muscovite in plates perpendicular to the direction of application of the dynamic forces. Nowhere is this gneissic structure as pronounced as in the Baltimore gneiss. At other times the granite presents a very massive appearance, no gneissic structure being visible. Megascopically, feldspar, quartz, biotite and muscovite are easily distinguished. Under the microscope the feldspar is found to be principally an acid plagioclase, which extinction angles show to be of the albite-oligoclase series. A subordinate amount of orthoclase is also present. The mica is usually considerably smaller in quantity than the feldspar. Biotite occurs in irregular plates. Most of the muscovite is probably secondary, although a small amount is undoubtedly primary. Hornblende is sometimes found in small quantities, but never sufficient to be considered anything more than an accessory constituent.

DIABASE

Although a number of diabase dikes of considerable extent have been found intruding both the gabbro and the granite in Cecil County, thus far only four short diabase dikes have been mapped in Harford County, all of them within the main gabbro belt. These dikes differ from those in Cecil County in the amount of metamorphism to which they have been subjected. Where outcrops are not available the diabase dike usually

reveals its presence by the number of cubical boulders scattered about the surface. These boulders almost invariably possess a coating of rusty yellowish-red material caused by weathering. Where exposures show the contact between gabbro and diabase it is found to be clear and distinct. There is no transition zone between the two types of rock, and no contact metamorphism. When a fresh specimen of diabase can be obtained it shows a greenish-black color with very fine grain. Usually the individual mineral grains cannot be distinguished without the aid of the microscope. Under the microscope it is at once apparent that the rock has been subjected to considerable metamorphism, although the ophitic texture is still plainly visible. The occurrence of the plagioclase indicates that it was the first mineral to crystallize. Plagioclase crystals have lath-like forms with idiomorphic shapes. The other chief constituent of the rock is a green, usually compact hornblende which acts as a matrix for the plagioclase. In a few cases remnants of pyroxene are found enclosed in the hornblende. The relation of the pyroxene to the hornblende shows that the latter mineral is a secondary alteration product of the former. The hornblende often contains minute crystallites of a clear, colorless mineral arranged parallel to the cleavage lines. Because of their small size it is impossible to determine accurately the optical properties of these bodies, although they correspond quite closely to those of quartz. In the majority of cases the plagioclase crystals have been altered to an aggregate of epidote and zoisite. These aggregates are so arranged that the ophitic texture has still been preseverd. Determination of the extinction angles of the unaltered plagioclase gives values corresponding to a composition of about $Ab_{25}An_{75}$. The plagioclase thus belongs to the labradorite-bytownite series. Magnetite is frequently present in small isolated grains. The presence of a small amount of chlorite in a few of the sections indicates some weathering of the hornblende.

The diabase dikes of Cecil County are very similar in occurrence to those of Harford County. In Cecil County, however, these dikes have been subjected to much less metamorphism than those of Harford

County. Leonard[29] states that the diabase of Cecil County is composed of lath-shaped crystals of feldspar, irregular grains of augite, and a little magnetite; and Bascom[30] says that the constituents are "remarkably fresh," although she notes some alteration of pyroxene to green hornblend and chlorite. Instances of the alteration of the usual constituents of diabase to hornblende, chlorite and epidote are very common in the literature. Williams[31] has carefully described diabasic rocks from the Menominee and Marquette districts of Michigan with well-developed ophitic texture in which the augite has been altered to fibrous or compact green hornblende and the feldspar to epidote or saussurite. Finckh[32] has noted a diabase with ophitic texture intrusive into the gabbro of northern Syria, in which pyroxene has been uralitized and feldspar altered to epidote. Similar alterations of ophitic diabase have been described by Loughlin,[33] Palache,[34] and many others.

CONTACT PHASES

Along or near the southern border of the main gabbro belt there are several small districts in which rock types are found with compositions and textures quite different from the principal rock types of the region. The rocks of these districts will be considered in detail.

One of these districts lies about half a mile to the east of Berkley near the west bank of the Susquehanna. It has an east-west trend, and is not more than an eighth of a mile in width nor more than a half-mile in length. The predominant rock of this area is a quartz epi-diorite, that is, a rock having the mineralogical composition of a quartz diorite, but in which some of the essential constituents are secondary alteration products. The transition between this rock and the hypersthene gabbro to the north is concealed under the cover of soil. Outcrops are few and far between. Megascopically the rock is holocrystalline,

[29] Leonard, A. G., Sm. Geol., vol. xxviii, 1901, p. 155.
[30] Bascom, F., Mary and Geol. Survey Cecil County, 1886, p. 141.
[31] Williams, G. H., U. S. Geol. Survey Bull. 62, 1890, pp. 138–146, 168–175.
[32] Finckh, L., Zeits. deutsch. geol. Gesell., Bd. L, 1898, p. 143.
[33] Loughlin, G. F., U. S. Geol. Survey Bull. 492, 1912, p. 102.
[34] Palache, C., Univ. Cal. Dept. Geol. Bull., vol. I, 1896, p. 174.

medium to fine-grained, with a greenish-gray color. In the hand specimen clear, glassy, bluish quartzes, feldspar (both clear and milky), hornblende, biotite, and a small amount of pyrite can be seen. Under the microscope the rock is seen to be composed chiefly of quartz, basic plagioclase, saussurite, chlorite, hornblende and pyrite. The feldspar is in part basic plagioclase, usually showing zonal development. Measurement of extinction angles shows the interior to have a composition of labradorite-bytownite, while the outer zone has a composition of andesine-labradorite. Usually the feldspar has been more or less completely altered to a mixture of epidote and secondary untwinned albite. The large quartz grains are either single individuals or they have been crushed into mosaic aggregates. Undulatory extinction is very common, both in the large grains and in the particles making up the mosaics. Green hornblende is another of the principal constituents, sometimes making up half of the rock. Although no pyroxene can be detected in the section the hornblende has all the characteristics of a secondary mineral. The fibrous variety is very prominent. Chlorite also occurs in considerable quantities, evidently produced as a decomposition product of the hornblende. Biotite is present only in isolated particles.

South of this district meta-gabbro, consisting mostly of amphibole and chlorite, makes its appearance. This is succeeded by the ordinary meta-gabbro, and just to the south of this is found a rock which apparently marks a transition zone between ordinary hypersthene gabbro and quartz epi-diorite like that half a mile to the north. Megascopically this is a greenish-gray rock of varying grain in which can be seen glassy quartz grains (as large as $\frac{1}{4}$ inch in diameter), greenish-black amphibole, and milky feldspar. The microscope shows the rock to be composed of saussurite, augite or diallage, quartz, chlorite, hornblende, phlogopite, zircon, and garnet. The saussurite is made up of large secondary albite crystals, usually without twinning, which act as a matrix for great numbers of crystallites of epidote and zoisite. Diallage is present in various stages of alteration to hornblende and chlorite. Chlorite, particularly, is very abundant in this rock. Quartz is either

in large grains, often crushed, or in veinlets with mosaic fabric. Phlogopite is fairly abundant. It is recognized by its occurrence in irregular plates with low index of refraction, fairly high double refraction, very small optic angle (practically 0°), and negative optical character. Small crystals of zircon, characterized by good crystal form, very high index of refraction, high double refraction, and positive uniaxial character, are frequently found. Garnet is also a common accessory constituent of the rock. The presence of phlogopite and garnet indicates the influence of a kind of contact action between the typical hypersthene gabbro and this more acid phase.

Because of soil covering there is no continuous outcrop, and therefore the gradations between the transition rock and the quartz epi-diorite itself cannot be observed. About a quarter of a mile south of the transition phase there is an exposure showing material very similar in character to that of the quartz epi-diorite in the area east of Berkley. Megascopically this rock is grayish-green with phenocrysts of clear, glassy quartz grains as large as a quarter of an inch in diameter. The groundmass is green with a decidedly laminated appearance. Under the microscope the rock is seen to be composed of quartz, saussurite, chlorite, hornblende, biotite, pyroxene, and pyrite. Quartz usually occurs as a mosaic aggregate, although single large grains are sometimes seen. Saussurite here consists of epidote and secondary albite, the albite acting as matrix for the epidote. Chlorite is present in fairly large quantities, evidently the result of the weathering of secondary hornblende. Green hornblende, usually fibrous, is quite common in this rock. The thin section sometimes shows a remnant of diallage surrounded by this fibrous hornblende, although in most instances the pyroxene has entirely disappeared. The area itself is wedge-shaped and half a mile wide at its broadest part. The contact with the Baltimore gneiss to the south is not exposed, but it seems very probable that this phase continues to the contact with the Baltimore gneiss without a recurrence of the typical hypersthene gabbro.

Another type of rock, evidently the result of contact metamorphism, is found near the border of the gabbro area just south of Darlington.

Megascopically it has the appearance of an augen-gneiss. Numerous eyes of a milky white color, the largest an inch in diameter, are closely imbedded in a groundmass of chlorite laminae. The eyes are only a fraction of an inch apart in some places. The chlorite laminae are wrapped about the feldspar eyes in the manner characteristic of augen-gneisses. The rock is not very resistant and on exposed surfaces weathers easily to a rusty brown color. Crinkling and kneading of the rock indicate that it was at one time quite plastic and viscous.

Under the microscope the eyes are seen to be composed of acid plagioclase of the albite-oligoclase series. Pressure subsequent to crystallization has elongated the crystals, although they still retain their cleavage faces and some suggestion of their original crystal form. The groundmass is made up of chlorite, quartz, acid plagioclase, and tourmaline with a small amount of biotite. Quartz and feldspar occur as fine grains in mosaic aggregates. Fine plates and fibers of chlorite with the characteristic low double refraction are abundant. Sometimes these plates are arranged in radiating aggregates, but usually they have a roughly parallel direction. With the naked eye this parallel arrangement of the chlorite laminae is still more apparent. Tourmaline in long, slender crystals with the characteristic strong absorption and triangular or six-sided cross-section is present in fairly large quantities. The effect of dynamic metamorphism is better seen in the groundmass than in the eyes, for the chlorite laminae have been drawn out and bent, and the slender tourmaline crystals have been broken.

Because of lack of exposure the transition between this contact augen-gneiss and the Baltimore gneiss cannot be seen. As will be shown later there seems to be but little doubt that this is a contact phase of the Baltimore gneiss.

Immediately to the west of this augen-gneiss, in the region including Mountain Hill, there is a large area, two and a half miles long and from one-half to three-quarters of a mile wide, in which rocks somewhat similar to the quartz epi-diorite of the area east of Berkley are found.

Megascopically these are coarse to medium-grained, holocrystalline rocks, gray in color. Schistosity is usually lacking. Quartz, feldspar,

biotite and hornblende are visible in the hand specimen. Quartz is often present in fair-sized, clear, glassy grains much like those of the Berkley area.

Under the microscope quartz, basic plagioclase, secondary hornblende, and biotite appear as the predominant minerals. Garnet, magnetite and pyrite are the usual accessory constituents. A little pyroxene (probably diallage) is sometimes present. Quartz occurs as large single individuals, often crushed into mosaic patterns. The primary feldspar is a basic plagioclase in which zonal developments are almost always found. Measurement of maximum extinction angles in the zone at right angles to (010) gives values of 40° for the interior of the feldspar and usually 27° for the outer zone. These values correspond to compositions of $Ab_{30}An_{70}$ (labradorite-bytownite) for the interior of the crystal, and $Ab_{50}An_{50}$ (andesine-labradorite) for the outer zone. Unlike the plagioclase of the typical hypersthene gabbro these crystals often show well-developed terminations and clear-cut crystal faces. Metamorphism has had some effect upon these epi-diorites, for the plagioclase has often been altered to saussurite, a mixture of zoisite, epidote, and secondary albite. Hornblende usually occurs as the fibrous green variety, although compact forms are sometimes seen. It is undoubtedly secondary, as in a few instances remnants of pyroxene can be seen undergoing alteration to hornblende. Biotite is also quite common in these rocks, usually appearing in large irregular flakes, and exhibiting the characteristic basal cleavage, strong pleochroism (deep brown to light yellow), very small axial angle with negative optical character, fairly low index of refraction, and medium double refraction. Inclusions in hornblende, biotite, and primary feldspar are numerous in these epi-diorites. Garnet is a very common inclusion in all three minerals. It is recognized by its high index of refraction, isotropic character, and well-developed rhombic dodecahedral form.

The presence of biotite and the absence of chlorite and any decided schistosity are characters which distinguish these epi-diorites from those of the Berkley area. In that area the schistosity and the presence of chlorite are probably due to the greater degree of metamorphism to

which the rocks have been subjected. In fact, the very presence of chlorite laminae has probably given the appearance of schistosity to the rock.

About one mile south of Gibson there is another very small area of epi-diorite. The rock here is almost identical with that of the Mountain Hill area. Immediately adjoining this is a small area containing augen-gneiss very similar to that of the area near Darlington. In a few places in this area the feldspar eyes are not well developed, but the feldspathic materials have been concentrated into lenses about which the chlorite laminae are wrapped.

DIFFERENTIATION AND CONTACT METAMORPHISM

Although the same minerals are to be found in general throughout the main mass of the unaltered hypersthene gabbro, there is a great deal of variation in individual specimens, even in those that have been collected within a few feet of each other. These variations are principally due to differences in size of grain and to differences in the relative quantities of the essential minerals present. As already noted the rock may be so feldspathic in some places that the pyroxenes become very subordinate, while in other places feldspar may decrease in quantity so much that the rock becomes a pyroxenite. Abrupt variations in grain are also common. Although no definite cause can be assigned for these rapid variations, they are undoubtedly due to differences in physical conditions in different parts of the magma. Differences in temperature and pressure might easily cause differences in rates of crystallization and thus in size of grain as well. Such differences in temperature and pressure would also cause variations in chemical composition through changes in rates of diffusion, etc., and thus there would be a difference in the relative quantities of minerals present in the solidified rock. The fact that the same essential constituents are present throughout the main gabbro area would seem to indicate, however, that in general composition and physical conditions did not vary greatly in different parts of the molten magma.

On the other hand, the epi-diorites show that there were decided, although local, differences in chemical composition and physical conditions within the areas where these rocks are present. In comparison with the whole gabbro area these epi-diorite areas are quite small. The petrography of these four areas at once shows the similarity in composition of their rocks. Indications of the presence of original pyroxene are very apparent, although the pyroxene itself has often been wholly altered to secondary hornblende. Zonal feldspars have been formed in all these districts, and these zonal feldspars show approximately the same composition. Biotite is a common mineral constituent, although some of the districts show a greater development of biotite than others. Garnet is also frequently found, although it may be regarded as an accessory constituent of these rocks. Chlorite, it is true, is present in large quantities in the epi-diorites of the two northern regions while there is very little in the rocks of the two other epi-diorite regions. Its presence in the northern regions may be easily explained by the exposure of these regions to weathering. Both of the northern areas are very close to the Susquehanna River, where relief is very distinct and marked and where, consequently, circulating waters have much greater activity.

Leonard[35] has described quartz diorites and quartz-mica-hornblende diorites from Cecil County very similar to the epi-diorites of Harford County. In Cecil County the diorites cover an area apparently greater than in Harford County but, like the epi-diorites of Harford County they are found only as a belt along the southern border of the main gabbro area. The same large blue quartz phenocrysts, zonal feldspars, hornblende and mica were observed. Leonard, however, noted the presence of orthoclase which has been found by the writer. He did not mention the presence of any traces of unaltered pyroxene, although he found fibrous hornblende to be very abundant. It is very probable that the quartz diorite and quartz-mica-hornblende diorite of Cecil County belong to the same type of rocks and have the same origin as the quartz epi-diorite and quartz-mica epi-diorite of Harford County.

[35] Leonard, A. G., Am. Geol., vol. xxviii, 1901, pp. 140–146.

An examination of the location of the epi-diorite areas shows at once that they are all found at or near the contact of the gabbro with the Baltimore gneiss. Two of these areas adjoin areas in which a peculiar augen-gneiss is found, a rock which is very evidently the result of some contact action. The contact of the epi-diorite with the augen-gneiss has not been discovered, but the augen-gneiss has been strongly folded and kneaded so that it gives the suggestion of having been in a semi-viscous state at some time in its history. It seems quite probable that were the direct contacts revealed they would show a transition zone between the augen-gneiss and the epi-diorite. Such a graduation has often been shown to be a common occurrence at contacts with intrusive rocks.

The epi-diorite shows considerable difference in composition from the typical hypersthene gabbro. The principal distinguishing feature of the epi-diorite is the presence of the large blue quartzes. Zonal feldspars are common in these rocks, but they have never been observed in the hypersthene gabbro. The interior of the zonal feldspar is slightly more acid than the typical feldspar of hypersthene gabbro, while the outer zone is decidedly so. Garnets also are present in the epi-diorites but are exceedingly rare in the hypersthene gabbro. Biotite is never found in hypersthene gabbro of this region, although it is a frequent constituent of the epi-diorite. Nevertheless the epi-diorite shows distinctly a closer relationship to the gabbro than it does to the Baltimore gneiss. The presence of pyroxene or the alteration products of pyroxene at once distinguishes this rock from the Baltimore gneiss. The epi-diorites are massive, rarely showing a gneissic structure except in the two northern districts, where a schistosity has been developed consequent upon the formation of chlorite. Hornblende is often fibrous in the epi-diorite, whereas in the Baltimore gneiss it is usually compact with distinct cleavage angles and fairly well-formed crystal faces. The basicity of the feldspars in the epi-diorite is a characteristic that must distinguish it from the Baltimore gneiss.

The epi-diorite thus shows by the presence of pyroxene, its general location, and the character of the feldspar, that it has undoubtedly been

derived from the magma of gabbroic composition, while the presence of quartz and the greater acidity of the feldspar would indicate that there had been an addition of material from a more acidic source. The explanation which seems to fit the facts is that the gabbro magma locally assimilated some of the Baltimore gneiss. The assimilation of material of a more acidic composition would cause the formation of a slightly different suite of materials, like that found in the epi-diorites. The zonal feldspars were the result of continually increasing acidity in the solution from which they crystallized.

It is also probable that the magma from which the epi-diorites were formed remained molten longer than the rest of the gabbro magma. In the larger of the two epi-diorite areas found close to the Susquehanna River there is a transition zone developed between hypersthene gabbro and epi-diorite in which there is a rock whose mineral assemblage would indicate that some contact action had taken place between the hypersthene gabbro and the epi-diorite. This rock has already been described. The presence of phlogopite, which is not found in either the gabbro or the epi-diorite, would suggest contact action. Zircon and garnet are present in unusual quantities. The longer period of fluidity of the epi-diorite was probably due mostly to the greater quantity of gases held in solution by the epi-diorite than by the gabbro. Gases would be likely to collect near the outer part of the molten magma, and they would probably also be absorbed by the magma through action on the Baltimore gneiss. The assimilation of material from the Baltimore gneiss may have also lowered the melting point, although more acidic rocks are generally thought to have higher melting points. Cases are often cited where mixtures of two substances have lower melting points than the substances themselves. That the intrusive magma had some effect upon the Baltimore gneiss is clearly shown by the formation of augen-gneiss and by the crumpling and wrinkling of the gneiss near the contact in several places. The indications of softening of the gneiss are unmistakable. If the actual contact between the gneiss and the gabbro could be seen still greater effects on the gneiss might be observed.

The augen-gneisses, so often found near the epi-diorite bodies, show every evidence of having been derived from the Baltimore gneiss. The feldspar is an acidic plagioclase, quite characteristic of the gneiss. No basis plagioclase is present. Quartz, which is always abundant in the augen-gneiss is also characteristic of the Baltimore gneiss, while it is very rare in the gabbro. The exceedingly well-developed gneissic structure at once indicates a close relationship to the Baltimore gneiss. In places the formation of eyes is only suggested, although the feldspathic materials are concentrated into lenses. The segregation of feldspathic bands is not uncommon in the Baltimore gneiss. Tourmaline is no doubt the result of pneumatolytic action. The development of chlorite in the augen-gneiss is very similar to a development of a chlorite schist noted by Chatard[36] at the contact of a dunite with hornblende gneiss. It is impossible to say what the original mineral was, from which the chlorite has been formed. Since hornblende is often a very abundant mineral in the gneiss, it seems quite probable that chlorite is a decomposition product of hornblende in this instance. The evidence of the structure and mineral composition of the augen-gneiss indicates that the heat of the intrusive body had raised the temperature and increased the activity of solutions within the gneiss. These solutions have deposited material around centers already present and thus the feldspar eyes have been built up. Augen-gneisses built up by such a process of deposition from solution have often been described. Sometimes this has been accomplished in schists or gneisses without the aid of heat from a neighboring igneous body. Berg[37] describes an augen-gneiss formed by the production of new quartz crystals between schist lamellae by deposition from circulating waters. Fenner[38] mentions an augen-gneiss in the Highlands of New Jersey, concerning which he says:—"Certain phenomena suggest that a force of crystallization may at times have been an effective factor in separating the layers. Aggregates of microcline and quartz crystals in the form of augen are seen,

[36] Chatard, T. M., U. S. Geol. Survey Bull. 42, 1888.
[37] Berg, G. E. W., K. Preuss. geol. Landesanst. Jahrb., Bd. xxviii, 1907, p. 647.
[38] Fenner, C. N., Jour. Geol., vol. xxii, 1914, p. 605.

inclosed by curving bands of schist." Fenner concludes that the pre-Cambrian gneiss of that region was caused by the injection of a thinly fluid granitic magma between the layers of an original rock of laminated structure. Williams[39] has described a case of contact metamorphism in the rocks of the Cortlandt series near Peekskill, New York, where mica schists have been greatly affected by the intrusion of a mica diorite. At some distance from the contact the mica schists are highly crystalline, but not much crumpled or metamorphosed. "As we follow them, however, across the strike they become more and more puckered and filled with lenses or eyes of quartz containing garnet and other minerals. In the schists themselves are developed staurolite, cyanite and garnet. The intensity of the metamorphic changes is directly proportional to the nearness of the schists to the massive rocks." Judd[40] has noted many instances of increase in the growth of feldsgar in massive rocks after solidification. He says (op. cit. p. 185):—"That, as a result of contact metamorphism, many well-defined mineral species are developed in the midst of solid rocks, the crystals growing at the expanse of and deriving their materials from the surrounding detrital fragments, has long been recognized." Harker[41] in a study on the migration of material during the metamorphism of rock masses concludes that the size of individual crystals of secondary minerals increases toward the contact with the intrusive rock. This, he thinks, is due to the fact that migration of material within a rock mass undergoing metamorphism has more latitude when the temperature is higher. Van Hise[42] thinks that contact effects are often brought about by heat and increased action of circulating waters near a molten magma. Not only the formation of the feldspar eyes but also the pronounced development of chlorite in the Harford County augen-gneiss was probably caused by the increased activity of the heated solutions.

The augen-gneiss one mile south of Gibson seems by its location to be more of an inclusion in the gabbro than a true contact rock. The

[39] Williams, G. H., Am. Jour. Sci. (III), vol. xxxvii, 1888, p. 255.
[40] Judd, J. W., Quart. Jour. Geol. Soc. London, vol. xlv, 1889, p. 182.
[41] Harker, A., Jour. Geol., vol. I, 1893, p. 577.
[42] Van Hise, C. R., Mon. U. S. Geol. Survey, vol. xlvii, 1904, p. 488.

lack of exposures between this place and the Baltimore gneiss, however, makes the location of any definite contact impossible.

From a review of the evidence given above, therefore, it is very probable that the augen-gneiss is a phase of the Baltimore gneiss produced by the heating and increased activity of solutions within the Baltimore gneiss because of the proximity of the molten gabbro magma. together with the action of some pneumatolytic solutions from the gabbro magma.

Contacts of the granite with the gabbro are not usually visible, but good exposures of gabbro and granite within a very few feet of each other have been observed. Nowhere has any decided contact metamorphism of either the gabbro or granite taken place. In one place granite has intruded the gabbro in the form of a relatively narrow dike about a mile long. Some of the specimens from this dike appear slightly harder and less friable than specimens of granite collected from other exposures in the region. There has been no change because of contact action in size of grain, texture, or kinds of minerals developed in the granite.

On a geologic map of Harford County published by the Maryland Geological Survey in 1904, the gabbro is shown extending across the county line into Baltimore County. Examination of exposures at or near the county line shows that the gabbro belt dies out or is covered by Baltimore gneiss before it reaches the county line. The Baltimore gneiss in this region is a very hornblendic, dark-colored phase, sometimes quite massive in appearance and often resembling gabbro very closely. A description of these rocks has already been given. The composition of the feldspar, the arrangement of the hornblende crystals, the abundance of quartz, and the structure indicate that the rocks here are to be classified as Baltimore gneiss and not as hypersthene or meta-gabbro.

RELATION TO BASIC INTRUSIVES OF ADJOINING AREAS

While in many respects the hypersthene gabbro of Harford County is very similar to the gabbros described from Baltimore County and Cecil

County, Maryland, Delaware and Pennsylvania, it is lacking in some phases characteristic of these other areas and shows some phases that thus far have not been described from the other areas.

Williams was the first to describe gabbros from the region around Baltimore. Gabbro occurs in the Baltimore region in a few areas of irregular shape. Hypersthene gabbro is found very similar to the hypersthene gabbro of Harford County, in which bytownite, hypersthene and diallage are the only essential primary constituents. Intimately associated with hypersthene gabbro is gabbro-diorite, which has essentially the same physical characteristics and the same mineral content as the meta-gabbro of Harford County. The gabbro-diorite has been produced from the hypersthene gabbro through the alteration of pyroxene to hornblende by the action of regional metamorphism. The gabbro-diorite often shows the alteration of feldspar to saussurite as well. Peridotites and pyroxenites are associated with the gabbro, but are a younger eruption. Gabbros and pyroxenites and peridotites were probably derived from the same parent magma. Williams has described one specimen of olivine gabbro from the Baltimore region. So far no olivine gabbro has been found in Harford County.

The basic intrusives of Cecil County have been described by Leonard and by Bascom. The main gabbro area in this county is a continuation of the gabbro belt of Harford County. There are also a few smaller isolated areas of gabbroic rock. Here are found hypersthene gabbro and meta-gabbro (gabbro-diorite) so prominent in Baltimore and Harford counties, although norite is the predominant phase in Cecil County. The norite is a hypersthene-bytownite rock with no essential diallage. Norite and hypersthene gabbro belong to the same intrusive mass, and are simply differentiation phases of that mass. Two specimens of olivine norite have been described by Leonard. Intrusions of pyroxenite and peridotite are found. Here too they are seen to be younger than the gabbro. Dikes of diabase, pyroxenite, peridotite and pegmatite cut the norite and gabbro. Diorites, very similar in composition to the epi-diorites of Harford County, form a narrow strip along the southern border of the gabbro. These rocks have been described.

The belt of gabbro continues from Cecil County, Maryland, through Delaware. The gabbros of Delaware have been described by Chester, who found in them several phases quite different from the gabbros of Maryland. In all of the gabbros and associated rocks of Delaware quartz is an abundant accessory constituent. The predominant type is hypersthene gabbro quite similar to that of the Maryland areas, with the exception of the presence of quartz. By addition of brown hornblende which Chester thinks may be original the hypersthene gabbro passes into a gabbro-diorite. This gabbro-diorite becomes hornblende gneiss with the imposition of a gneissic structure. By the addition of biotite and quartz as important constituents the hypersthene gabbro becomes "gabbro-granite." This may be closely related in composition and origin to the quartz-mica epi-diorite of the Harford County region. The "norite" which Chester has described is a rock "composed mainly of a very fine-grained mixture of quartz and plagioclase, which, in hand specimens, appears quite homogeneous; in this ground mass are porphyritically developed larger grains of hypersthene and magnetite with generally a few shreds of biotite" (p. 22). The gabbro-diorites (metagabbros) of Iron Hill, Delaware, as described by Chester, are very similar to those described by Williams from the Baltimore region. The alteration of feldspar to epidote in the Delaware region has also been noted.

Gabbros closely related to those of Maryland have been described by Bascom from the region included in the Philadelphia folio. The area mapped as gabbro includes norite, hypersthene gabbro, and true gabbro. These rocks are differentiated by the presence or absence of hypersthene or diallage. In all three forms of gabbro, labradorite or labradorite-bytownite is the usual feldspar present. This region is exceptional in that garnet is a usual accessory constituent in the gabbro. The development of secondary hornblende does not seem to be as prevalent in the gabbro of this area as it is in the gabbro of Maryland.

AGE RELATIONS OF GABBRO AND ASSOCIATED ROCKS

The age relations of some of the rocks associated with the gabbro are still quite uncertain. Lack of good exposures at contacts and the complicated structure of the Piedmont Plateau make determination difficult.

There is no doubt, however, that the gabbro is younger than the Baltimore gneiss. In Harford County gabbro is intrusive into the gneiss. The contact action of the gabbro on the gneiss also indicates that the gabbro is younger than the gneiss. In Cecil County the same age relations probably hold true as at least part of the granite (the Port Deposit granite) which has been considered older than the gabbro is undoubtedly a phase of the Baltimore gneiss. Williams and Keyes considered the gneiss of the Baltimore region to be the oldest formation present, for there it has been intruded by granite, gabbro, and still more basic igneous bodies. The evidence of the younger age of the gabbro is conclusive in the Philadelphia region where there are a number of dikes and small stocks of gabbro which have been intruded into the Baltimore gneiss. Another line of evidence which indicates the younger age of the gabbro is the amount of metamorphism which it has undergone compared to the metamorphism of the Baltimore gneiss. The Baltimore gneiss everywhere shows indications of having been acted upon by powerful orogenic movements. The Baltimore gneiss is probably made up of ancient sedimentaries and igneous complexes but the original nature of these rocks has been so obscured that it is now practically impossible to draw any distinction between original sedimentary and igneous bodies. All of the phases of this formation have been intensely laminated with the mineral constituents drawn out into parallel bands. The gabbro, on the other hand, rarely shows any traces of gneissic structure, and where such structure is present it is much less pronounced than in the Baltimore gneiss.

The granite which appears in the Harford County region in dikes and tongues of considerable extent is younger than both gabbro and gneiss. It is not only intrusive into the gneiss but in one place is found as a short dike within the gabbro area. The same relation of gabbro to

granite holds true in Baltimore County. Keyes[43] found that "the granites penetrate and break through all the rocks of the region—gabbros, diorites, pyroxenites, and gneisses." Hobbs[44] (26) found considerable evidence in the region around Ilchester, Maryland, that the granites are younger than the gabbros. Numerous dikes of granite cut the gabbro in this region. In Cecil County, however, evidence as to the age relation of granite and gabbro is not so clear. Leonard[45] concludes that there is no definite evidence to show the age relation of gabbro and granite. He notes, however, that pegmatite dikes are intrusive into the gabbro and says in this connection:—"The pegmatites are more recent than the basic rocks and serpentines and since the latter have originated from non-feldspathic types the acid dikes are also younger than most of the peridotyte and pyroxenyte." Grimsley[46] has made a detailed study of the granites of Cecil County. He has divided the granites into two districts; a northwestern district which is called the Rowlandville area, and a southeastern one called the Port Deposit area. The granites of the Port Deposit area are much more foliated and gneissoid than those of the Rowlandville area. Grimsley concludes (op. cit. p. 103) that all of the granites "are probably older than the more basic gabbros which bound them on the north and northwest," but he also says, in comparing the Rowlandville and Port Deposit areas that "the rocks near Port Deposit . . . . represent either an older intrusion, or a zone of maximum dynamic action."

Bascom also divided the granites of Cecil County into two areas; an area of more gneissic biotite granite (the Port Deposit area), and an area of less gneissic hornblende-biotite granite (the Rowlandville area).

In discussing these two granites and their relation to the gabbro it is significant that the Cecil County geological map, published by the Maryland Geological Survey in 1902, shows no gabbro intrusions into the area of the Rowlandville granite while there are several large intru-

[43] Keyes, C. R., 15th Ann. Rept. U. S. Geol. Survey, 1894, p. 738.
[44] Hobbs, W. H., Dissertation, Johns Hopkins University, 1888.
[45] Leonard, A. G., Am. Geol., vol. xxviii, 1901, p. 174.
[46] Grimsley, G. P., Jour Cincinnati Soc.Nat. Hist., vol. xvii, 1894.

sions of gabbro into the area of the Port Deposit granite. It is also noteworthy that no contacts between the gabbro and Rowlandville granite have been found that would throw any light on the age relations. It is quite possible that two ages of granite may be represented and that one, the Rowlandville, may be of the same age as the granites of Baltimore and Harford counties which have been considered to be younger than the gabbro. The other, the Port Deposit granite, is no doubt a facies of the Baltimore gneiss.

The pegmatite dikes which are intrusive into the gabbro furnish more evidence on the relative age of the granite. Williams[47] divides the pegmatites of the Baltimore region into two classes; (1) segregation pegmatites which are really quartz veins carrying a little feldspar, and (2) intrusive pegmatites which show the usual coarse-grained aggregates of quartz, feldspar, biotite or muscovite, and other accessory minerals. Pegmatites of the latter class show characteristics which caused Williams to conclude that they were of intrusive origin. They agree essentially with the granitic intrusives in mineralogical and chemical composition: they are often very close to some granitic body: their composition is quite independent of that of the rocks which surround them. At the same time the presence of unusual minerals in the pegmatites makes it seem probable that the intrusion was accompanied by pneumatolytic action or by the presence of considerable water. The one large pegmatite dike which has been found within the gabbro area shows the same characteristics that Williams found in the intrusive pegmatites of the Baltimore region. This dike is undoubtedly younger than the gabbro. It therefore seems probable that the pegmatite here is contemporaneous with the granite, just as it has been found to be in the Baltimore area.

The quartz veins which can be traced in many places in the gabbro area by the trails of quartz boulders which are left on the surface undoubtedly had an entirely different origin. Orogenic movements subsequent to the solidification of the gabbro opened cracks and fissures which were later filled by minerals, principally quartz, deposited by

[47] Williams, G. H., 15th Ann. Rept. U. S. Geol. Survey, 1894, p. 679.

circulating waters. Sometimes these veins are represented only by small and isolated lenses while at other times they become so large that it is possible to quarry the quartz. Tourmaline and occasionally feldspar are also present in these veins. The formation of quartz veins probably was not confined to any one geologic period.

Concerning the age relation of the ultra-basic rocks to the gabbro there seems to be a close agreement between the students of the related areas of Maryland and Pennsylvania. The relation of the peridotites and pyroxenites to the gabbro in the region around Ilchester indicates that they are younger than the gabbro. Both Leonard and Bascom concluded after a study of the field associations in Cecil County that the rocks from which the serpentines were derived were younger than the gabbro. Bascom considered the serpentines of the Philadelphia region to be contemporaneous with or subsequent to the gabbro in age. Johannsen found the same relations to hold true in Harford County. Here the bodies which by alteration have formed serpentine are usually in the shape of dikes or stocks. These bodies vary widely in size. In several places serpentine is encountered within the gabbro area. The occurrence in the field shows it to be of an intrusive nature. No transition zones are found between the typical hypersthene gabbro and the serpentine and the contacts are usually sharp and abrupt. Within the gabbro there are two or three small areas of pyroxenite which show gradations into the true hypersthene gabbro but these seem to be local differentiation phases of the gabbro and not to be related to the typical serpentines so often found.

The relation of the serpentine to the granite is not as definite as that of the serpentine to the gabbro. The association of the two types in the field in Harford County does not give any real clue as to their age relations. The evidence of one locality in the Ilchester region led Hobbs to the conclusion that the ultra-basic rocks were a later intrusion into the granite. Keyes (33, p. 692), however, thinks that the granites are the youngest eruptives of the Baltimore region, intrusive into both the gabbros and the ultra-basics.

The relation of the diabase to the other intrusive rocks of Harford

County is still a matter of some uncertainty. Several diabase dikes break through the gabbro and are therefore certainly younger than the gabbro. At present there is no conclusive evidence to show that they are younger than the granite or the serpentine. More work in this region may reveal the presence of diabase dikes cutting the granite and the ultra-basic rocks. Both Leonard and Bascom have considered the diabase dikes of Cecil County to be continuations of the great Triassic dike which Lewis[48] traced through eastern Pennsylvania as far as the Maryland border. Certain characteristics distinguish the diabase of Harford County from that of Cecil County. In the specimens of diabase described from Cecil County both the augite and plagioclase are comparatively unaltered, the development of secondary hornblende and epidote being noted only in a few instances. In Harford County, however, unaltered pyroxene is rarely found and the alteration of plagioclase to epidote is very common. Secondary hornblende and epidote are the usual constituents of the diabase. It is evident that the diabase of Harford County has undergone much more metamorphism than has that of Cecil County. This does not, of course, prove that the Cecil County diabase is younger than the Harford County diabase but it is an indication that such may be the case. Diabase dikes have often been noted in other areas as intrusive into gabbros, apparently occurring as later off shoots of the parent magma. Loughlin in his investigation of the gabbros and associated rocks at Preston, Connecticut, has cited the occurrence of diabase dikes very similiar to those of Harford County in which the pyroxene has been altered to uralite and the feldspar altered to saussurite. These dikes have broken through the gabbro and Loughlin concludes that the upper portion of the main gabbro magma consolidated and became ruptured while the lower portion was still molten. The lower portion then welled upward into the net-work of fissures, forming dikes. Diabase of two district ages has been described in eastern Pennsylvania,[49] one pre-Cambrian and the other Triassic. The pre-Cambrian diabase is characterized by considerable

[48] Lewis, H.C., Proc. Am. Phios. Soc., vol. lxxii, 1885, pp. 438–456.
[49] Jonas, A. I., Am. Mus. Nat Hist. Bul., vol. xxxvii, 1917, pp. 173–181.

alteration; augite has been altered to chlorite, and feldspar to saussurite. This diabase has been called pre-Cambrian because it has undergone considerable alteration and because it is intrusive only into pre-Cambrian rocks among which gabbro of apparently the same age as the Harford County gabbro is included. The other type of diabase is intrusive into Triassic shales and shows none of the alteration effects so characteristic of the pre-Cambrian diabase. It is quite probable that the diabase of Harford County is also much older than the Triassic diabase of Cecil County and the areas farther north. These older dikes may in fact be off-shoots of the same parent magma from which the gabbro came.

Any decision as to the true age of the gabbro and related intrusives of Harford County must rest in large part upon the age of the mica schists and phyllites which border these rocks on the north and west and into which dikes and stocks of the ultra-basics have been intruded. If these schists and phyllites are to be correlated with the Wissahickon mica gneiss of eastern Pennsylvania which Bliss and Jonas have found to be pre-Cambrian in age, then it is very probable that the intrusives also are pre-Cambrian. The meta-gabbro of eastern Pennsylvania has been called pre-Cambrian by these authors and there seems to be little doubt that this rock and the gabbros of Maryland are part of the same great intrusion.

A study of the field relations and associations of the different eruptive types—granite, gabbro, and ultra-basic rocks—at once suggests that they all originated from a common source. Williams was the first to propose such an origin for the eruptive series in the neighborhood of Baltimore. Referring to this series he says:—"While this wide range of petrographic types can not be positively shown to have originated from a single magma, their relationships in the field are so intimate and the instances of the gradual passage from one to the other are so common, that this seems not to be an improbable hypothesis." Leonard considered the eruptives of Cecil County to be differentiation products of a single parent magma. Bascom also thinks it highly probable that the igneous rocks of Cecil County are the differentiation prod-

ucts of a single magma, differentiation taking place both before and after intrusion. The conclusion that these types were derived from a single parent magma through differentiation before and after intrusion seems to be the one most probable for the eruptive series of the Maryland Piedmont Plateau. Examples of series of eruptive rocks, differing considerably in composition in each member, but nevertheless considered as having been derived from a common parent magma, have often been cited in the literature. Notable examples are the Cortlandt Series and the igenous complex of Garabal Hill in the Southern Highlands of Scotland.[50]

SUMMARY

1. In Harford County, Maryland, gabbro has been intruded into the ancient, highly crystalline schists and gneisses. The gabbro has the shape of a belt reaching almost all the way across the county but only three and a half miles wide at its broadest part. Its shape and the structure of the gneisses into which it has been intruded suggest that the gabbro may be in the form of a sill or sheet with a dip to the southeast.

2. For purposes of description two predominant varieties of gabbro have been recognized in this area, hypersthene gabbro and meta-gabbro. Study of the two types shows, however, that the meta-gabbro is only an alteration product of the hypersthene gabbro, due to the action of regional metamorphism. These two varieties grade into each other almost imperceptibly.

3. With the exception of a few small areas the whole of the unaltered gabbro is a hypersthene gabbro in composition, almost always containing the same mineral constituents. The relative amounts of these mineral constituents vary widely and abruptly, however. The grain of the rock also varies abruptly. These variations are thought to be due to change in physical conditions within the solidifying magma.

4. Near the contact of the gabbro with the Baltimore gneiss are areas

[50] Dakyns, J. R. and J. J. H. Teall, Quart. Jour. Geol. Soc. London, vol. xlviii, 1892, pp. 104–121.

which contain quartz epi-diorites and quartz-mica epi-diorites with a slightly coarser grain and a different mineral composition from the main mass of the gabbro. Field relations and microscopic study of these rocks indicate that they have been formed by assimilation of some of the adjacent Baltimore gneiss. They probably solidified somewhat later than the main mass of the gabbro.

5. Augen-gneisses are often associated with these epi-diorites. Their structure and mineral content indicate that the augen-gneisses have been derived from the Baltimore gneiss principally through contact action of the gabbro. The heat of the intrusive gabbro magma has increased the activity of solutions within the gneiss, causing feldspar eyes to be deposited and perhaps increasing the formation of chlorite. Pressure and heat from the gabbro have also caused kneading and crinkling of the gneisses.

6. The gabbro belt of this county is probably a part of the same intrusion as the gabbros, hypersthene gabbros, and norites of eastern Pennsylvania, Delaware, Baltimore County and Cecil County. At present, with the scarcity of evidence in Harford County and adjoining regions, it is impossible to determine exactly the age of the gabbros and associated intrusives. If the schists of the northern part of the county which have been invaded by the serpentine are to be correlated with the Wissahickon mica gneiss, then it seems probable that the age of the intrusives is pre-Cambrian.

7. The gabbro shows quite clearly its age relative to the associated igneous formations—granite, altered peridotites and pyroxenites, and diabase. The gabbro is undoubtedly younger than the Baltimore gneiss into which it is intrusive. The granite, however, is younger than the gabbro, as is indicated by their field relations in Harford County and Baltimore County. The serpentines, altered peridotites and pyroxenites, are also younger than the gabbro, although their age relative to the granite is not indicated by any evidence so far available in Harford County. The diabase is certainly younger than the gabbro, while evidence from other sections of the Piedmont Plateau indicates that it is probably also younger than the other igneous formations. Differences

in degree of alteration in this diabase and in the diabase of Cecil County seem to show that the diabase of Harford County was formed at an earlier date. It may be closely related in time to the other igneous intrusions.

8. Evidence from this and adjoining areas makes it seem very probable that all the intrusive bodies except those which form portions of the Baltimore gneiss are products of a common parent magma, considerable differentiation having taken place in the parent magma before intrusions of the present igneous formations began.

9. Regional metamorphism and the activity of solutions which often accompanies that force have profoundly altered all the intrusive rocks of the region as well as the sedimentaries. Peridotites and pyroxenites have been converted to serpentine; gabbro has been altered to metagabbro, with change of pyroxene to hornblende and feldspar to saussurite; granite has become somewhat foliated; and diabase has been uralitized.

VITA

Herbert Insley was born at Nanuet, New York, May 16, 1893. His early education was received at the public school at Nanuet and the High School at Spring Valley, New York. He entered Amherst College in September 1910. In his sophomore year he entered Hamilton College at Clinton, New York, and graduated there in June, 1914, with the degree of Bachelor of Science. He entered Johns Hopkins University in the fall of 1914, where his time was devoted to the study of geology, petrography, and physical chemistry. He held a University Scholarship in 1916–17 and a University Fellowship in 1919. The summer vacations were spent in field work in geology in part in the Adirondack Mountains as field assistant to Dr. W. J. Miller of the New York Geological Survey, and in part as field assistant on the Maryland Geological Survey. From July, 1917 to August, 1918 he was laboratory assistant and assistant physicist for the United States Bureau of Standards, engaged in the petrographic study of ceramic materials. On September first he enlisted in the United States Army, from which he received his discharge on January, 1919.